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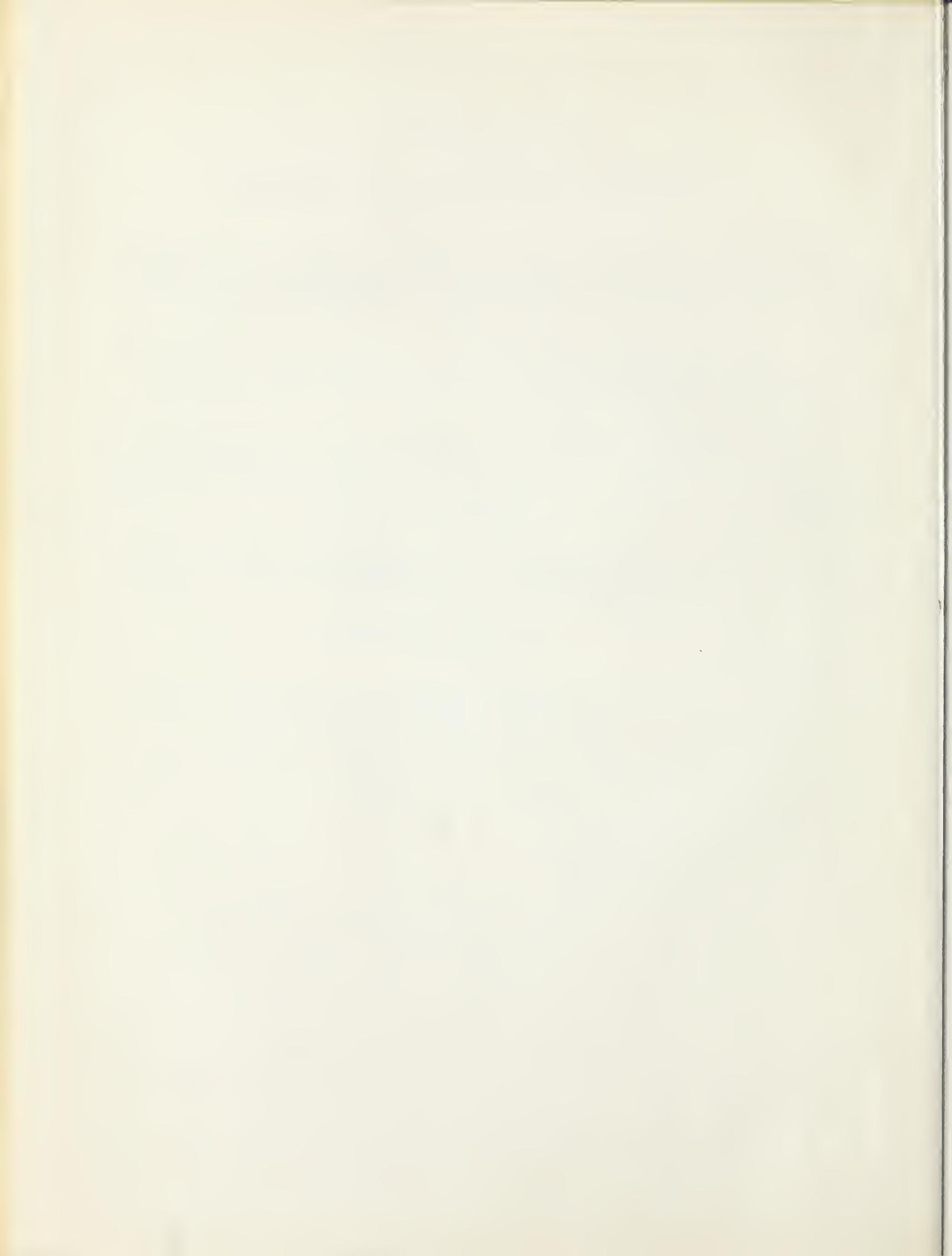
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THE UNIVERSITY OF ALBERTA

THE EFFECT OF MOTIVATION ON UNDERWATER  
PERFORMANCE IN TWO STRAINS OF INBRED MICE

by

Jack Norman Dardick

A THESIS

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## ABSTRACT

The purpose of this study was to determine the relationship between motivation and performance in two strains of inbred mice. The source of motivation was underwater air deprivation. Four levels of air deprivation were employed; 0, 4, 8, and 12 seconds. The performance measure was swimming speed in a 2-foot underwater straight-away. BALB/cJ and C57BL/6J mice were the two strains used as subjects.

The results showed that there was a significant curvilinear relationship between level of air deprivation and swimming speed, in the first half of the straight-away. That is to say, swimming speed increased almost linearly up to 8-seconds deprivation and then levelled off between 8 and 12-seconds deprivation. No such relationship occurred in the second half of the straight-away. These findings were discussed in terms of a frustration hypothesis.

The two strains performed somewhat differently on the task. Further, the behavior of the two strains differed considerably during the underwater detention periods. In an attempt to explain these findings, it was hypothesized that the Ss of the BALB/cJ strain were behaviorally rigid, while those of the C57BL/6J strain were behaviorally flexible.



ACKNOWLEDGEMENTS

I would like to express my sincere appreciation to the following people who assisted in various ways in this study: Lorne Yeudall, Barry MacKay, Ron Ramsay, who acted as recorders; Paul Degroot, who made a considerable contribution in the construction of the apparatus; and a special thanks to my wife, Darlene, who not only helped record the data but also typed the rough drafts.

Jack N. Dardick.



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## INTRODUCTION

### Statement of the Problem

The present study is an empirical investigation to determine the functional relationship between motivation and performance in two strains of laboratory mice.

### Source of the Problem

The major source of the present investigation was a study by Broadhurst (1957). Broadhurst, using rats as subjects, was primarily concerned with demonstrating the generality of the Yerkes-Dodson law in an underwater discrimination task. As a preliminary step, however, he was obliged to determine the effect of various levels of motivation on performance. It is this relationship that is of major concern in the present study.

Broadhurst controlled motivation through the use of air deprivation. That is to say, the Ss were held underwater for various periods of time before being released into an underwater straight-away. Consequently, Ss released immediately after submergence, or held only for a short period before release, were considered to be mildly motivated, while those deprived of air for longer periods were considered to be more highly motivated. Underwater swimming speed was the performance measure.

Using female rats who had had previous training in underwater swimming, Broadhurst obtained swimming speeds in a 4-foot underwater straight-away following delays (air deprivation) of 0, 5, 10, 15, 20, and 25 seconds. A plot of air deprivation (motivation) against



swimming speed (performance) revealed a curvilinear relationship between these variables (see Fig. 1). That is to say, swimming speed increased almost linearly for deprivations up to about 10 seconds, remained relatively constant for deprivations of 10 to 20 seconds, and decreased slightly at 25 seconds. Conceptually speaking, then, increasing drive<sup>1</sup> facilitated and enhanced performance up to an optimal level at which performance stabilized, despite further increase in drive intensity. Broadhurst speculated that the decrease in performance from 20 to 25 seconds deprivation may have been due to the effects of anoxia. Since Broadhurst's Ss had had previous training in underwater swimming, it seems reasonable to assume that the relationship he obtained represents an accurate picture of performance at or near the learning asymptote.

#### The Present Study.

Over the past few years, the present investigator has been involved in a number of genetic studies which employed inbred mice as subjects. This species has rarely been used as the experimental population in any motivational study which attempted to systematically manipulate the independent variable. For this reason, and since Broadhurst's technique is such a recent innovation in motivational research, the combination of inbred mice and Broadhurst's technique was of interest, and from this the present study emerged. The problem,

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<sup>1</sup> Brown (1961) uses the terms "drive" and "motivation" as synonyms. They are similarly used in the present investigation.



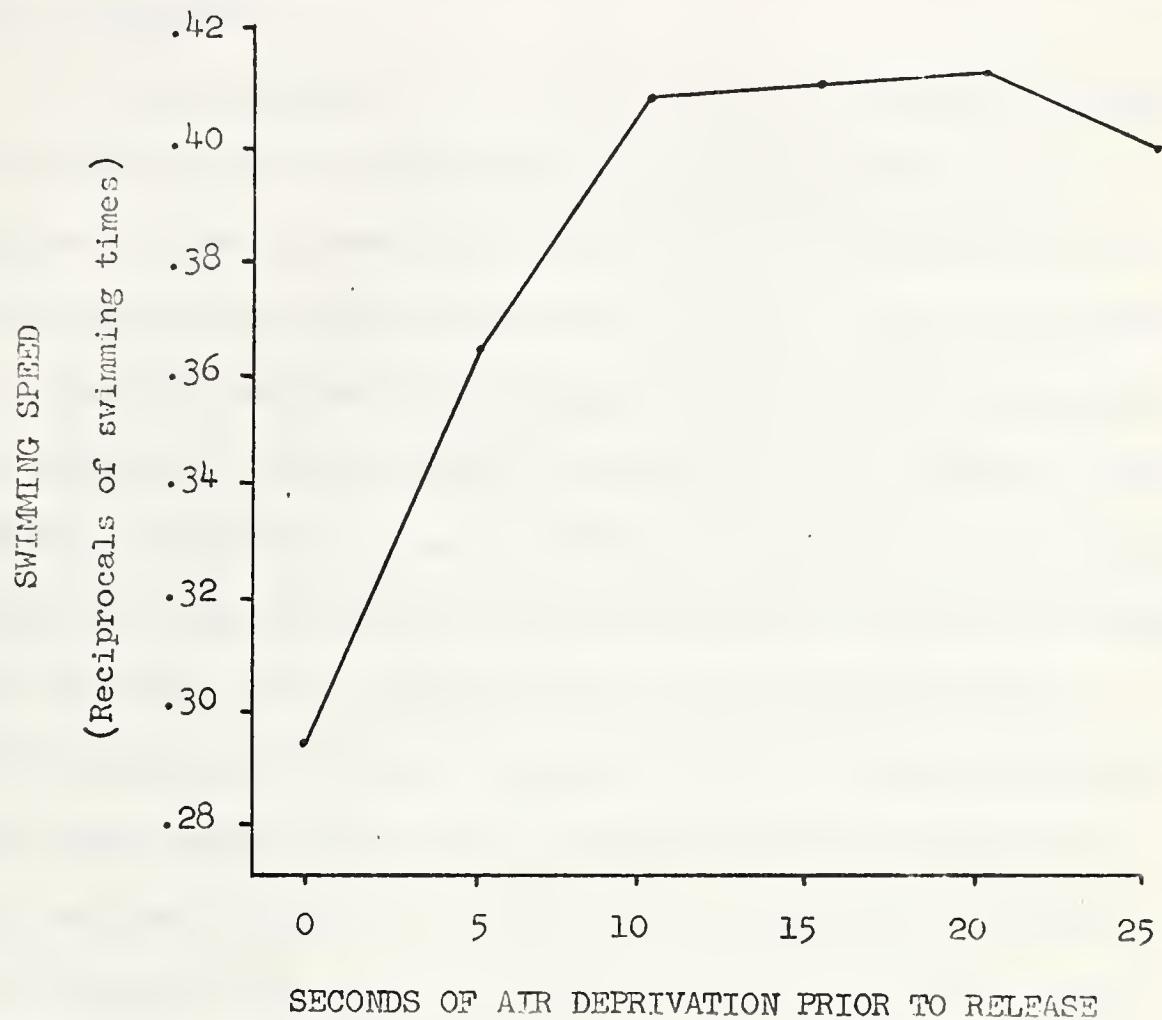


Fig. 1. The relationship between speed of underwater swimming (performance) and intensity of air deprivation (motivation). Each point represents the mean time for 20 female rats. (Adapted from Broadhurst, 1957).



stated below, is strictly empirical. Thus, a discussion of motivational theory at this point is unwarranted. However, in a later chapter a possible theoretical integration of the results will be suggested.

The question asked in this investigation is stated as follows: if air deprivation is used as the source of motivation, and underwater swimming speed as the measure of performance, what is the nature of the relationship between various levels of motivation and subsequent performance when inbred mice are used as subjects?

Broadhurst's study appears to provide the only relevant data from which an hypothesis can be derived. A search of the literature (reviews by Rethlingshafer, 1963; Duffy, 1952; Brown, 1961; Eriksen, 1957; and Hebb, 1955) revealed that the relationship between motivation and performance is highly specific to the experimental conditions. Brown (1961, p. 81) comments upon this problem and concludes that "difficult problems arise in designing experiments on motivational variables, and since known investigations differ so widely with respect to subjects, responses, and procedures, no single function can be held uniquely representative of the relation between response strength and deprivation time." The results of the present investigation will be compared with the findings of other studies in a later chapter. However, as a result of Broadhurst's work, it is expected that the relationship between motivation and performance will be curvilinear, i.e., the level of performance will rise, with increasing drive, up to an optimal drive value at which performance will stabilize despite further increases in drive intensity.



The selection of subjects presented a minor problem since the inbred mouse population is composed of a number of genetic strains which differ behaviorally. It was felt that there would be some value in comparing the performance of two strains which showed large differences in performance on other types of behavioral tests. After consulting a study by Thompson (1953), C57BL/6 and BALB/c were the strains selected as subjects for this investigation. Thompson compared fifteen mouse strains with respect to three types of behavior: food-drive (number of grams of food eaten in an open-field situation following food deprivation), emotionality (frequency of defecation in an open-field), and exploratory activity (number of square entries in a subdivided modified open-field). He found that the C57BL/6 strain had a significantly higher food-drive, a significantly lower rate of defecation, and were significantly more active than the BALB/c strain. The mean differences between these strains in terms of the three behaviors is presented in Table 1.

TABLE I

Mean Differences Between the C57BL/6 and BALB/c Strains in terms of Three Behaviors; Food-drive, Emotionality, and Activity

	Food-drive. No. of gms. eaten	Emotionality. % of Ss defe- cating	Activity. No. of squares entered
C57BL/6	162*	40**	361*
BALB/c	99	82	74

\* p < .01

\*\* p < .001



Royce and Covington (1960) have shown that these two strains also differ in conditionability in an avoidance learning situation. They found that all of their BALB/c sample conditioned within the upper limit criterion of 700 trials. The mean number of trials to the conditioned response for this group was 136.63. In the C57BL/6 strain, however, over one-half of the Ss did not condition within the upper limit criterion, and consequently, the results of the entire group had to be eliminated from the statistical analysis.

As a result of the knowledge of differences between these two strains, it is not unreasonable to expect that a performance difference will also be found in the present study. There is some basis for making a prediction as to the direction of the expected difference. Broadhurst (1957, 1958) has shown that emotionality, as determined by rate of defecation in an open-field, is a significant variable in the underwater swimming performance of rats. He found that emotional rats swam significantly faster than non-emotional ones, and interpreted this as reflecting a stronger drive in the emotionally reactive animals. The strains selected for the present study also differ in terms of this variable, the BALB/cJ strain being more emotionally reactive. Consequently, if a strain difference does occur, it would be logical to expect a difference in swimming speed, with the BALB/cJ strain being the faster. However, since these strains differ in terms of many organismic variables, e.g., activity, it is obvious that other hypotheses are tenable.



METHODSubjects

Thirty-five male Ss of each of two strains, C57BL/6J and BALB/cJ, (35 days of age on arrival) were obtained from the Jackson Laboratory. They were housed in individual cages, 9" x 4" x 5", which were placed in a single rack. The Ss were fed ad lib throughout the entire experiment. With the exception of the test periods, the laboratory was constantly illuminated so that no particular diurnal rhythm could be established. Except for the addition of fresh supplies of food and water and weekly cleaning, the cages were not touched nor the animals handled until testing began when the Ss were 65 days of age. (Cleaning of the cages caused minimal disturbance since it required only the removal of pans placed immediately below each row of cages.)

It is important to note that the Ss remained in their individual cages for the duration of the experiment. At no time did they have physical contact with one another. This isolation minimized any experiential effects of one S on another during training and testing.

Apparatus

The underwater swimming tank was a scaled-down version of the one used by Broadhurst (1958) for rats. It was constructed of clear  $\frac{1}{2}$ " plexiglass. The inside dimensions of the tank were



60" x 2" x 6". However, only the first three feet of the tank were used in the present study. An illustration of the entire apparatus is presented in Appendix 1.

The first six inches of the tank were occupied by a submersible starting cage, 6" x 2" x 3", with a guillotine door. It was constructed of white plexiglass with the exception of one side which was made of clear plexiglass for observational purposes. The pilot work made it clear that the starting cage was too large and that the Ss had difficulty in discriminating the door from the back wall since both were white. Consequently, for the present study, the cage was subdivided with a black plexiglass partition so that the chamber for the S measured 3" x 2" x 2". This modification facilitated emergence from the cage in two ways;

(1) it made the discrimination of the door easier for the S, and,

(2) the restricted size of the cage increased the probability, at the beginning of training, that random activity by the S would result in emergence rather than a deeper penetration into the starting cage.

The top and bottom of the starting cage was covered with fine plastic mesh which allowed the water to enter as the cage was submerged.

The last six inches of the tank were occupied by a plastic-mesh covered ramp, rising at a  $60^{\circ}$  angle from below the surface of the water. The distance between the starting cage and the ramp was



covered with 1/8" black plexiglass, 1" below the top of the tank.

This ceiling forced the Ss to swim the entire length underwater.

In order to record the starting time and the swimming time for the first and second foot, photoelectric beams were utilized. One photocell was located  $1\frac{1}{2}$ " from the guillotine door of the starting cage. From this the starting time was obtained. Another photocell was located in the middle of the tank, one foot from the first. Both of these light beams were projected vertically through the tank so that breaking of the beam was independent of the swimming depth. A third photocell was suspended from the escape ramp at a distance of one foot from the middle photocell. The light beam for this photocell was projected horizontally, just below the surface of the water. The three photocells were connected to three Stoelting 6-v. electric timers which were calibrated to one one-hundredths of a second.

Clear plastic inserts, covered with red filters, were placed in the black ceiling since the light sources for the two photocells were suspended over the top of the tank. The photocells were placed under the tank. In order to accomplish this, the tank was raised 6" above the base on which the entire apparatus was mounted.

The sequence of events was as follows: E pressed a switch which activated the first timer and, approximately at the same instant, manually raised the guillotine door; when S emerged and broke the first photoelectric beam, the first timer stopped (thus recording starting time) and the second one started; upon breaking



the middle beam, the second timer stopped (thus recording the time for the first foot) and the third one started; finally, as S emerged from the water breaking the last beam, the third timer stopped (and time for the second foot was recorded on this timer). Once the third beam was broken, a system of relays caused the circuit to remain open, thus preventing S from reactivating the last timer. Similarly, manual switches were connected in series between the other photocells and timers. In the event that the S doubled back after breaking the first two beams, the circuits could be opened, thus preventing reactivation of these two timers. The electric timers and the relays were reset manually at the end of each individual trial.

Water level in the tank was  $5\frac{1}{2}$ , 1/2-in. above the ceiling. Water temperature ranged from  $70^{\circ}$  to  $75^{\circ}$  F., while the air temperature was essentially constant at  $77^{\circ}$  F. The apparatus was surrounded on three sides by a covered enclosure painted a dull black. The only illumination was provided by two 60-watt bulbs suspended two feet above and slightly to the rear of the tank. Extraneous noise was masked by white noise from a Grason-Stadler Noise Generator (Model 901A). The noise level within the experimental room was not determined.

A large-faced Gra-Lab Universal Timer, operated by a footswitch, was used during training and test trials for determination of under-water detention periods. Since E manually operated this timer and also activated the one which recorded the starting time, it is



apparent that the underwater detention periods and the starting time were subject to experimenter error. Consequently, these times were not as accurate as the times for the first and second foot. The error effect was probably random.

#### Procedure

Pilot Study. In order to roughly define some of the variables in the underwater swimming task, the author ran a pilot study using 24 Ss from each of the C57BL/6J and BALB/cJ strains. The findings of this study which were incorporated into the present investigation are listed below.

- (1) Four levels of air deprivation, 0, 4, 8, and 12 seconds, were used in the pilot study. These deprivation values appeared to be sufficiently different so that clearcut performance differences could be obtained. Further, the highest deprivation level (12 seconds) did not seem to be too severe. That is to say, it did not deprive the Ss of oxygen to a point where the chance of drowning would be a problem. Consequently, these four levels were used in the present study.
- (2) No advantage is gained from using massed trials on individual days. There was a linear decrease in swimming speed over massed trials within days under all deprivation conditions, but the relationship between performances under the various deprivations remained constant over



trials. It appeared that this decrease was due to fatigue, an undesired variable. Consequently, spaced trials were used in the present study.

- (3) In the pilot study, the Ss were required to swim a distance of two feet underwater. It was observed that swimming speed was noticeably faster during the first foot. Since swimming distance is obviously a factor in performance, it was decided to maintain the same distance, but to record swimming times for both the first and second foot.
- (4) In the pilot study, learning to emerge from the starting cage appeared to be a significant factor which obscured swimming performance (since, following Broadhurst, only the time from the opening of the starting cage door until S surfaced at the other end of the tank was recorded). It was observed that starting time (time to emerge from the starting cage) appeared to increase linearly with increasing deprivation time. Further, it was evident that starting performance was different from the swimming measures, in terms of what was required from S to perform the task. Consequently, in the present study, this source of variation was isolated by recording the starting time separately from swimming time.
- (5) The pilot study revealed that a training period consisting of 20 trials was sufficient to adapt the



Ss to the apparatus and the conditions. Similarly, 60 test trials appeared to be sufficient to ensure that swimming speed reached an asymptote. Thus, the number of training and test trials for the present study was determined.

Experimental design. The design was a 4 x 2 factorial. Four levels of air deprivation were selected as sources of motivation, 0, 4, 8, and 12 seconds. Eight Ss from each of the two strains were run under each of the four experimental conditions for a total of 64 Ss (see Fig. 2). Three different swimming times were obtained, i.e., starting, the first foot, the second foot.

No. Strain Ss in each		Conditions (air deprivation in seconds)				Total
		0	4	8	12	
BALB/cJ		8	8	8	8	32
C57BL/6J		8	8	8	8	32

Fig. 2. Experimental Design

Training trials. When the Ss were 65 days of age, each S was given 20 training trials, 5 trials at each of the four deprivation levels. A random order of the trials was determined. This remained constant for all the Ss. The original design called for 5



spaced trials every 12 hours, and the first ten trials were run on this basis. However, pressure of time (the first ten trials required 15 hours to complete) dictated a modification, so that only five trials every 24 hours were given for the remainder of the training period and throughout the test period.

Thirty-five BALB/c's and thirty-three C57BL/6's received the full complement of 20 training trials. On any one trial, the strains were run alternately, i.e., a BALB/cJ followed by a C57BL/6J, followed by a BALB/cJ, etc. The intra-strain running order was randomly determined on the initial trial. This order remained constant for all subsequent trials. This meant that any S receiving a trial had to wait until all other Ss had been run on that trial before receiving the next trial. Consequently, the intertrial interval was approximately one hour in duration. Fecal material was removed from the tank and half of the water was changed at the end of every complete trial. The water was completely changed every five trials.

A trial was run in the following manner. S was lifted from his home cage by hand and placed in the starting cage. The Gra-Lab Timer was set at the predetermined deprivation time. The cage was then placed in the tank. At the moment S was fully submerged, the foot-switch was depressed to begin the deprivation interval. As a light on the clock signaled the end of this interval, E pressed a switch to start the first timer and simultaneously opened the guillotine door. When S emerged from the tank on the escape ramp,



the three times, i.e., starting, first foot, and second foot, were recorded. S was then removed from the escape ramp, placed in his home cage, and the home cage was replaced in the rack. One S of the C57BL/6J strain drowned during training.

Test trials. At the end of the training trials, 32 Ss were selected from each strain, the smallest Ss being rejected, and randomly assigned to one of the four deprivation intervals, i.e., 0,  $\frac{1}{2}$ , 6, and 12 seconds. These assignments remained constant for the duration of the testing period. To control for possible systematic changes in procedure or environment over a trial, eight groups, containing eight Ss each, were formed. In each group, both strains and all deprivation intervals were represented, i.e., the groups contained one S from each strain under each of the four deprivations. Random selection determined the order of running of these groups for the first trial. This first trial order was maintained throughout the entire testing period. Within each group the order of running was from the lowest to the highest deprivation, respectively. That is to say, both Ss, the BALB/cJ and the C57BL/6J, under 0-sec. deprivation were run. They were followed by both Ss under  $\frac{1}{2}$ -sec. deprivation. The Ss under 12-sec. deprivation were run last.

Sixty trials were given to each S on the same basis as the training, i.e., five spaced trials every 24 hours. The intertrial interval varied from 35 to 60 minutes.



RESULTS

Three swimming times, corresponding to the three units of the straight-away, i.e., the start, the first foot, and the second foot, was obtained for each S. These times were transformed into reciprocals (by dividing the time into 1) in order to avoid the possibility of heterogeneity of variance, which is often a problem when a time measure is the dependent variable (Edwards, 1963). Whether the variances of the untransformed data were heterogeneous was not determined. However, the reciprocal transformation has two additional features:

- (1) it reduces the size of the individual values which makes the computations in the ensuing analyses much easier, and,
- (2) it changes the time scores into speed scores which allows for the comparison of performances from different distances.

Performance in each of the three segments of the straight-away was analyzed separately.

Training Trials

No analysis of the training trials was undertaken. Since all Ss received the 20 trials, i.e., five trials at each of the four air deprivation levels before being randomly assigned to one of these levels for testing, it was assumed that because of equal treatment there would be only random differences between the deprivation groups at the beginning of testing.



Test Trials

As mentioned previously, each S received five spaced trials per day for 12 successive days, a total of 60 trials. Medians for each 5-trial block were computed. (An inspection of the data revealed that there was no specific trend over the five daily trials, as had been the case in the pilot study where massed trials had been employed.) The medians were then transformed into reciprocals to obtain speed scores.

In order to more easily ascertain when the learning asymptote had been reached, the learning curves were smoothed by blocking the data. To accomplish this, the data for each S was grouped into six successive 10-trial blocks by averaging the median speed scores for 2-day periods. That is to say, for each S the mean of the median speed scores of Days 1 and 2 was obtained, and similarly, means for Days 3 and 4, Days 5 and 6, etc., were computed. The treatment means for each strain were obtained by averaging the block means of the 8 Ss in each treatment group.

Learning curves, for each treatment group, consisting of the swimming speed scores over blocks of trials are presented in Figures 3, 4, and 5, for starting, the first foot and the second foot, respectively. Although these curves are interesting in themselves, they were not relevant to the main purpose of this thesis, since the test trials were given only to ensure that a stable level of performance would be reached, i.e., the learning asymptote. From an inspection of Figures 3, 4, and 5, it appeared



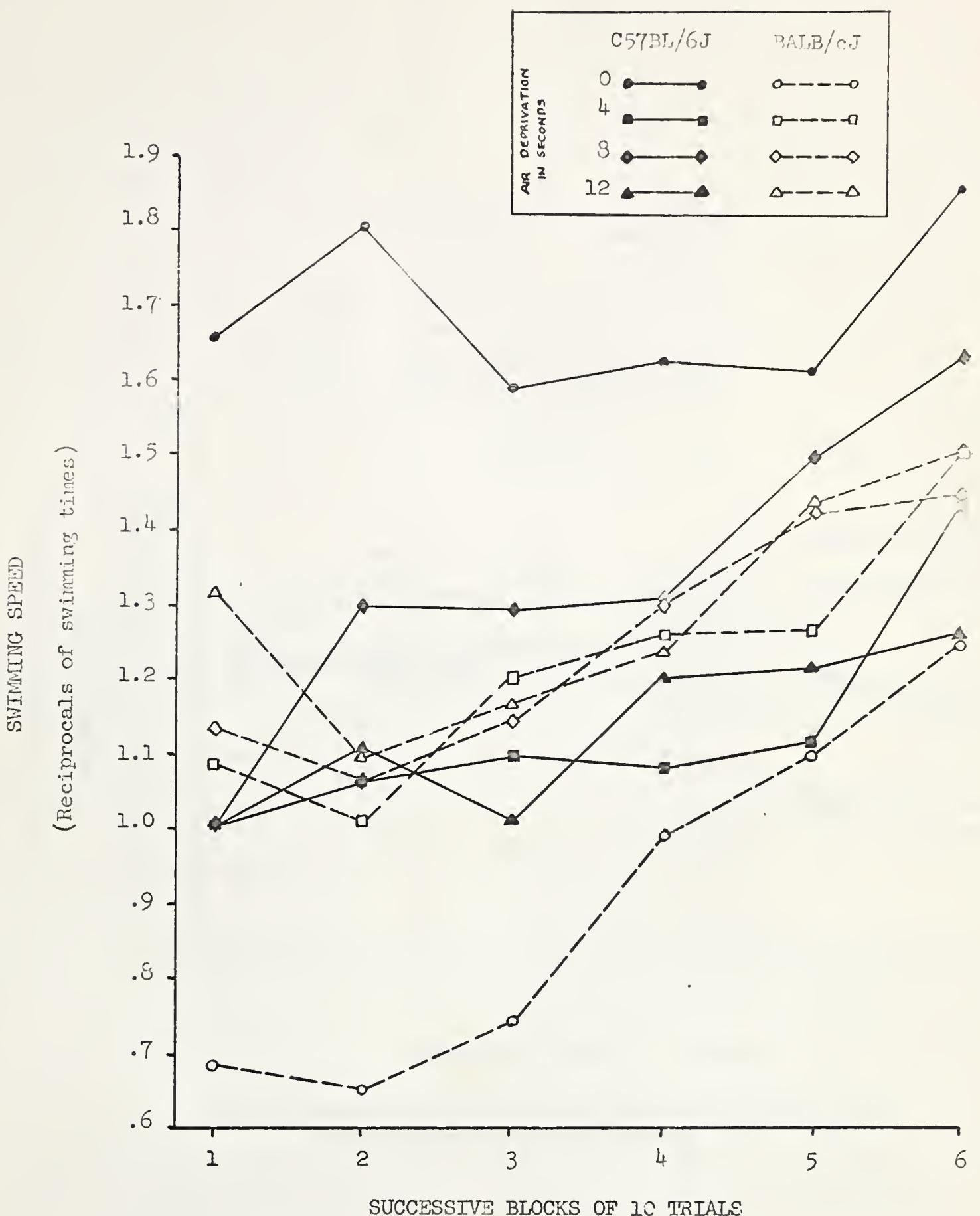


Fig. 3. Learning curves for starting for each treatment group.



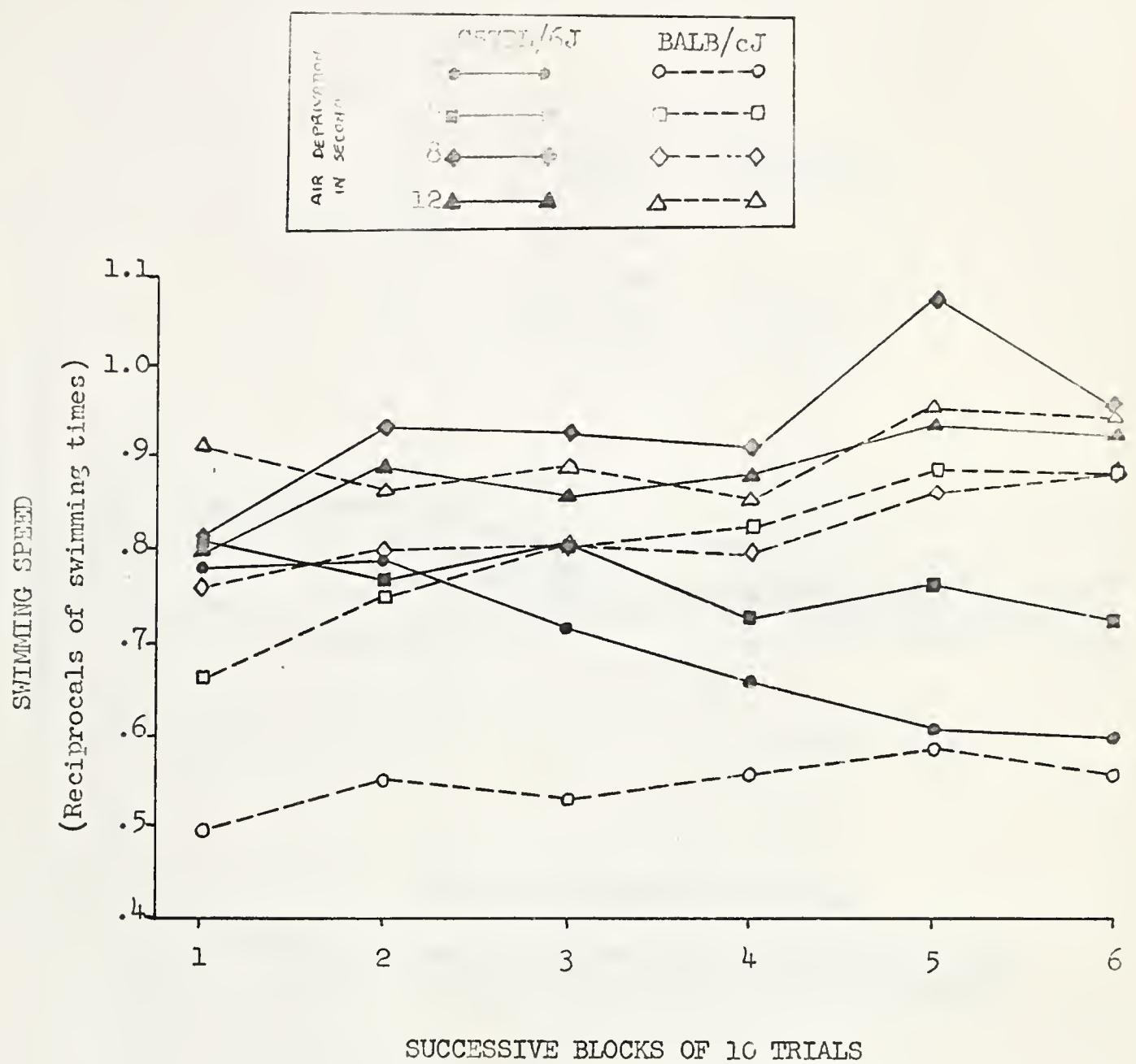
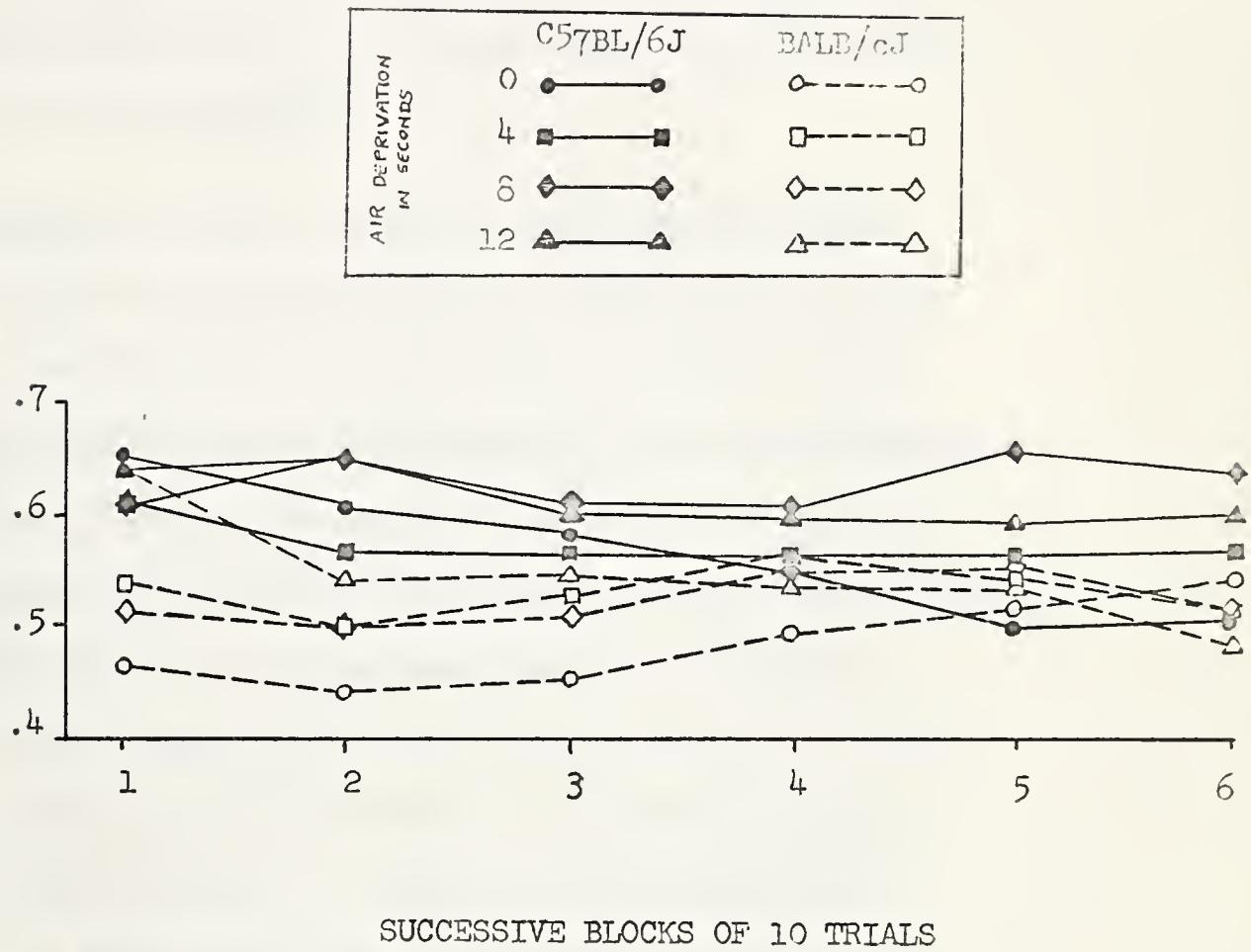


Fig. 4. Learning curves for each treatment group in the first foot of the straight-away.



SWIMMING SPEED  
(Reciprocals of swimming times)



SUCCESSIVE BLOCKS OF 10 TRIALS

Fig. 5. Learning curves for each treatment group in the second foot of the straight-away.



that learning asymptote had been reached by the fifth block of trials in the first and second foot, although not in starting.

In the ensuing analyses, a score for each S was obtained by averaging performance over Blocks 5 and 6, since, as was mentioned above, the primary interest was in relationship between deprivation level and swimming speed at the learning asymptote, not in learning.<sup>2</sup>

First Foot. Figure 6 shows the relationship between swimming speed and the duration of air deprivation for each strain in the first foot of the underwater straight-away.<sup>3</sup> In general, swimming speed increased with increasing duration of deprivation. Further, the shape of the curves for the two strains appeared to differ. To determine whether these effects were significant, the data was analyzed by an analysis of variance model suggested by Winer (1962, p. 233). The significance of the trend of the deprivation component was also computed (Winer, p. 273). A summary of these analyses is presented in Tables 2a and 2b, respectively. An  $F_{max}$  test revealed that the variances of the eight treatment groups were not significantly different. Therefore, homogeneity of variance can be assumed.

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<sup>2</sup> The justification for excluding trial Blocks 1-4 from the analyses lies in the fact that the trends of the learning curves in all three segments of the straight-away were significant (see Appendices 2, 3, and 4).

<sup>3</sup> The first foot swimming speed scores for all Ss in both strains is presented in Appendix 5.



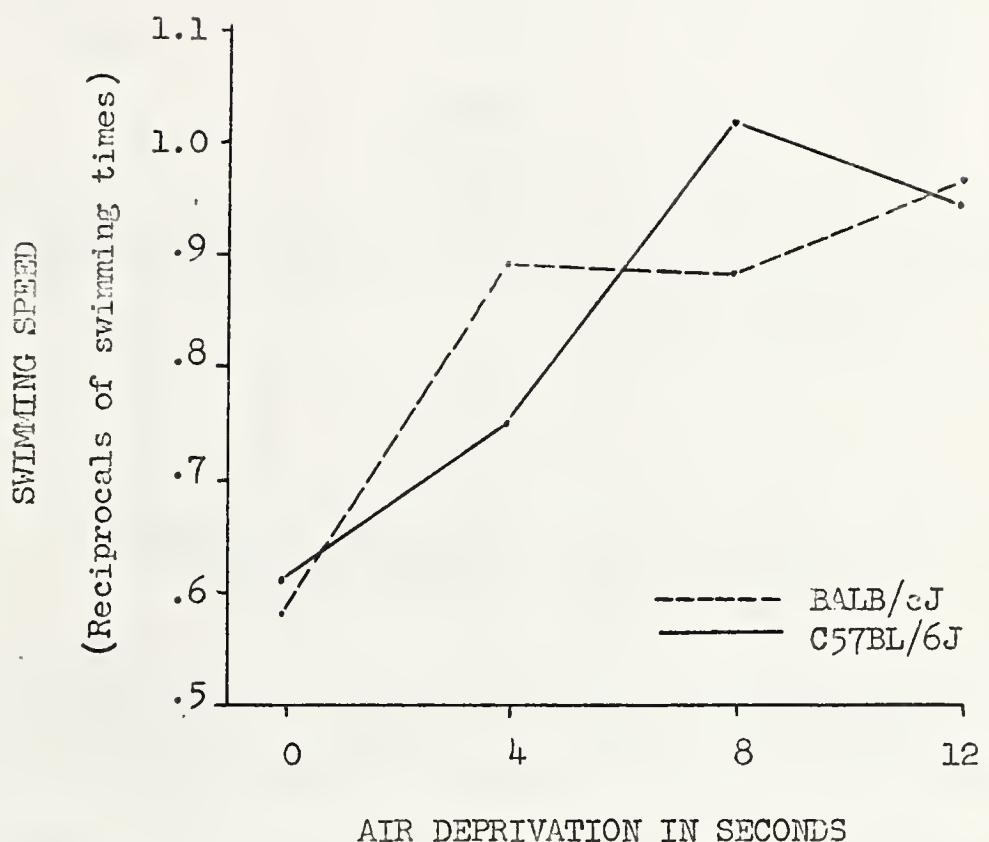


Fig. 6. Relationship between level of deprivation and swimming speed in the first foot of the underwater straight-away for each strain.



TABLE 2a

Summary of the analysis of variance for the effects of strain and deprivation on swimming speed in the first foot of the underwater straight-away

Source of variation	Sum of squares	df	Mean Square	F
Strain	.0003	1	.0003	
Deprivation	1.3229	3	.4410	14.46***
Strain X Deprivation	.1664	3	.0555	1.82
Error	<u>1.7088</u>	<u>56</u>	.0305	
	3.1984	63		

\*\*\*p < .005

TABLE 2b

Summary of the analysis of the trend of the deprivation factor for the first foot.

Source of Variation	Sum of Squares	df	Mean Square	F
Deprivation				
Linear	1.1234	1	1.1234	36.83***
Quadratic	.1980	1	.1980	6.49**
Cubic	<u>.0015</u>	<u>1</u>	.0015	
	1.3229	3		
Strain X Deprivation				
Linear	.0045	1	.0045	
Quadratic	.0000	1	.0000	
Cubic	<u>.1619</u>	<u>1</u>	.1619	5.31*
	.1664	3		
Error	1.7088	56	.0305	

\*\*\*p < .005

\*\*p < .025

\*p < .05



The analysis of variance showed that the main effect of deprivation was highly significant ( $p < .005$ ). This indicates that the swimming speed means for the various deprivation levels, averaged across strains, differed significantly. Since there was no evidence of strain differences (the main effect of strain and the strain x deprivation effect were not significant), the data for the two strains was combined to obtain a single motivation-performance function. This is presented in Figure 7.

From Table 2b, it can be seen that both the overall linear and quadratic components of the trend of the deprivation means were significant ( $p < .005$  and  $p < .025$ , respectively). The linear component was in an upward direction and accounted for  $1.1234/1.3229$  or 84.9 per cent of the variation due to deprivation. The quadratic component, which indicated that there was significant curvature in the trend of the means, accounted for  $.1980/1.3229$  or 15.0 per cent of the variation. Thus, for the first foot, the relationship between intensity of air deprivation and swimming speed, combined over strains, was curvilinear.

The cubic trend within the strains x deprivation interaction was also significant ( $p < .05$ ). This shows that there are two inflection points within the trend of each strain curve, and that these inflection points differ significantly between strains.

The swimming speed means and standard deviations for each strain, and the means for the combined data, are presented in Table 3. Duncan's new multiple range test (Edwards, 1963) was



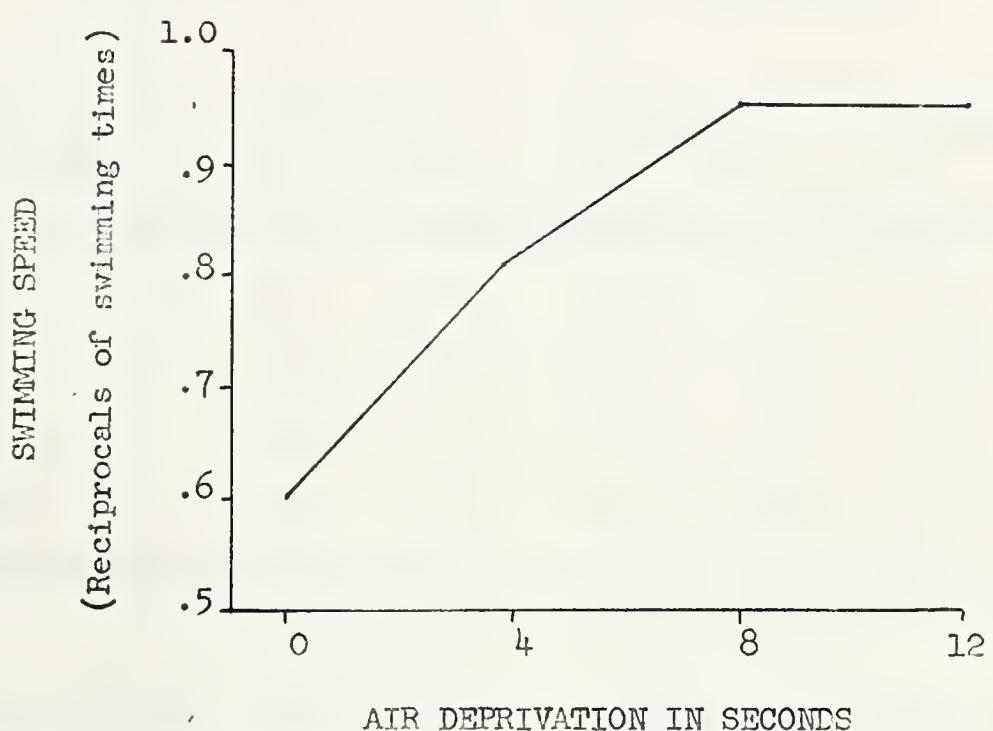


Fig. 7. Relationship between level of deprivation and swimming speed in the first foot of the underwater straight-away. Data for both strains combined.



used to test the significance of the differences between the means of the combined data. It revealed that the 0 and 4-second treatment means differed significantly from each other, while both of these differed significantly from the 8 and 12-second means ( $p < .05$ , in all cases). The 8 and 12-second means did not differ.

TABLE 3

Swimming speed means and standard deviations for each treatment group in the first foot of the straight-away.

Air Deprivation	C57BL/6J		BALB/cJ		COMBINED	
	$\bar{X}$	S.D.	$\bar{X}$	S.D.	$\bar{X}$	S.D.
0	.61	.09	.58	.11	.60	.10
4	.75	.17	.89	.22	.82	.20
8	1.02	.21	.88	.18	.95	.20
12	.94	.19	.96	.18	.95	.19

Second Foot. Figure 8 shows the relationship between air deprivation and swimming speed for each strain in the second foot of the straight-away.<sup>4</sup> Increasing duration of air deprivation had little effect on the performance of the BALB/cJ strain. However, the swimming speed of the C57BL/6J strain increased up to eight seconds deprivation, with a slight decrease at the 12-second

<sup>4</sup> The second foot swimming speed scores for all Ss in both strains are presented in Appendix 6.



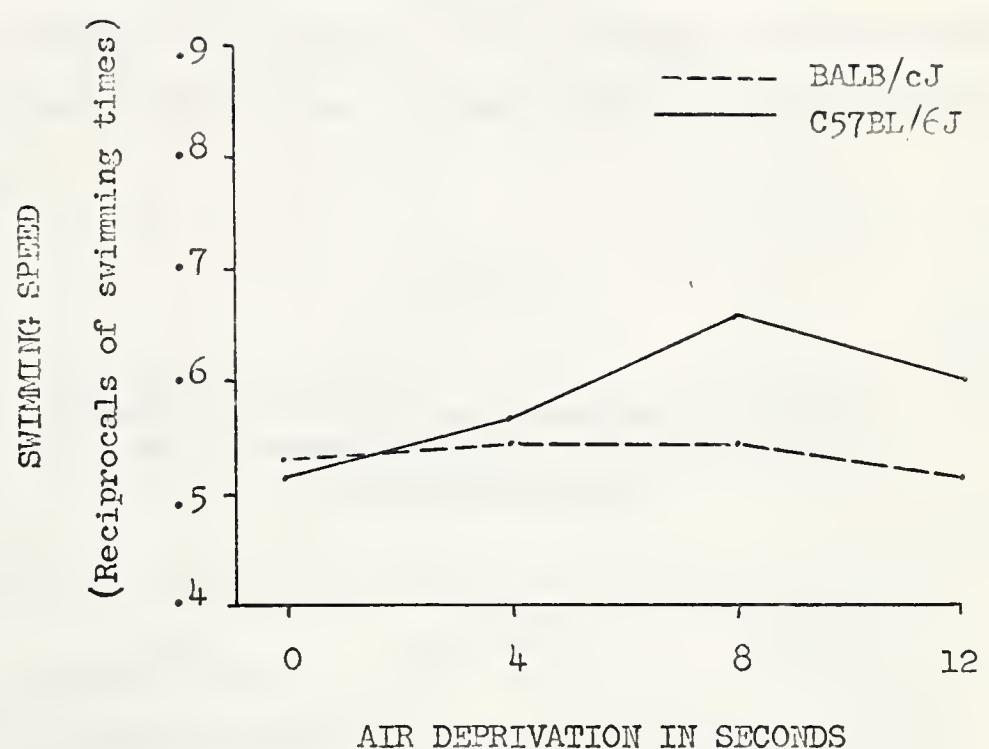


Fig. 8. Relationship between level of deprivation and swimming speed in the second foot of the underwater straight-away for each strain.



deprivation interval. There appeared to be a constant strain difference in swimming speed at the two highest levels of deprivation. As with the first foot, the significance of the factors was determined with an analysis of variance model suggested by Winer. An  $F_{max}$  test showed that the variances of the eight treatment groups were not significantly different. Hence, homogeneity of variance can be assumed. The means and standard deviations of the treatment groups are presented in Table 4.

TABLE 4

Swimming speed means and standard deviations for each treatment group in the second foot of the straight-away.

Air Deprivation	C57BL/6J		BALB/cJ	
	$\bar{X}$	S.D.	$\bar{X}$	S.D.
0	.52	.10	.53	.10
4	.57	.08	.54	.09
8	.66	.10	.54	.08
12	.60	.07	.52	.11

The summary of the analysis of variance presented in Table 5a reveals that the strain effect was significant ( $p < .025$ ). That is to say, when swimming speed was averaged over all levels of deprivation, the C57BL/6J strain swam significantly faster



than the BALB/cJ strain, in the second foot of the straight-away. The deprivation effect and the strain x deprivation interaction were not significant.

TABLE 5a

Summary of the analysis of variance for the effects of strain and deprivation on swimming speed in the second foot of the underwater straight-away.

Source of Variation	Sum of Squares	df	Mean Square	F
Strain	.0467	1	.0467	5.43*
Deprivation	.0476	3	.0159	1.85
Strain x Deprivation	.0433	3	.0144	1.67
Error	<u>.4808</u>	<u>56</u>	.0086	
	.6184	63		

\* p < .025

The analysis of the trend of the deprivation factor is shown in Table 5b. There were no significant differences in the linear, quadratic, and cubic components. Also within the strain x deprivation interaction, there were no significant differences in the linear, quadratic, and cubic components.

Duncan's new multiple range test was used to test the significance of the strain differences in mean swimming speed for individual air deprivation intervals. It revealed that only the strain means for the 8-second deprivation interval were significantly different ( $p < .05$ ).



TABLE 5b

Summary of the analysis of the trend of the deprivation factor in the second foot of the underwater straight-away.

Source of Variation	Sum of Squares	df	Mean Square	F
Deprivation				
Linear	.0170	1	.0170	1.98
Quadratic	.0206	1	.0206	2.41
Cubic	<u>.0100</u>	<u>1</u>	.0100	1.16
	.0476	3		
Strain x Deprivation				
Linear	.0303	1	.0303	3.52
Quadratic	.0075	1	.0075	
Cubic	<u>.0055</u>	<u>1</u>	.0055	
	.0433	3		
Error	.4808	56	.0086	

Although there was no statistical analysis of the difference in performance between the first and second foot, a comparison of Figures 6 and 8 reveals that overall swimming speed was appreciably slower in the latter.

Starting. As mentioned previously, the starting time had been recorded separately in order to obtain a measure of swimming performance in the straight-away uncontaminated by the factor of learning to emerge from the starting cage. A comparison of Figure 3 with Figures 4 and 5 reveals that this precaution was justified. The



factor of learning, as shown by the general increase in swimming speed over blocks of trials, appears to be more important in starting than in either the first or second foot. Moreover, starting differs from the first and second foot in that the learning asymptote was not reached.

In the light of the failure of the different treatment groups to reach learning asymptotes, an analysis of the relationship between swimming speed (mean of blocks 5 and 6) and level of deprivation would not have been meaningful since the relationships between curves were not stable at Blocks 5 and 6, i.e., they might have changed considerably if more trials had been given. However, it is apparent in Figure 3 that there were differences between the treatment means which could have had some systematic effect on subsequent swimming performance in the straight-away. To test for this effect, the Ss swimming speed scores for starting and the first foot were ranked across treatment conditions and a Spearman's coefficient of rank correlation was computed between these two scores, for each strain. For the C57BL/6J strain the correlation coefficient was .06 ( $t = .33$ ,  $df = 30$ ,  $p > .20$ ), whereas the correlation for the BALB/cJ strain was .70 ( $t = 5.37$ ,  $df = 30$ ,  $p < .001$ ). This means that for the BALB/cJ strain, the faster the emergence from the starting cage, the faster the swimming speed in the first foot of the straight-away. There appears to be no such relationship for the C57BL/6J strain.



Behavioral observations. Although no attempts were made to quantify it, there appeared to be a marked difference in the behavior of the two strains during the deprivation periods. The Ss of the C57BL/6J strain were very active and randomly explored the cage throughout the deprivation interval, though they generally oriented towards the door just before it was opened by E. The Ss of the BALB/6J strain, on the other hand, were much less active than the C57BL/6Js. Upon submergence of the cage, they generally took a position near the door and continued to claw at it vigorously until it was opened.

Some BALB/cJs exhibited other types of behavior, while swimming, which were essentially absent in the C57BL/6J strain. They would often swim part of the way down the straight-away, then suddenly stop, and begin to turn around and around. On some occasions it was necessary for E to remove them from the tank to save them from drowning. On other occasions, they would resume swimming but back towards the starting cage. Upon finding the door of the starting cage closed, they would reverse direction once again, swim down the straight-away, and finally emerge on the escape ramp.<sup>5</sup> Some Ss of this strain did not exhibit

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<sup>5</sup> Ss who exhibited this behavior, and/or had to be removed from the tank, naturally obtained very large swimming times (in the order of 20 - 25 seconds) for that trial. Only rarely did this occur on more than two of the five daily trials. Since a Ss' daily score was the median of each 5-trial block, there was little distortion due to these abnormally large times.



disorientation but would merely pause briefly, in some part of the straight-away, before continuing on to the ramp. The frequency of these responses appeared to decrease as the number of trials increased. No record was kept during testing of the trials in which these responses occurred.



DISCUSSION

The findings of this investigation can be summarized as follows:

- (1) In the first foot of the underwater straight-away, the relationship between intensity of motivation and performance, in terms of the variables employed in this study, was curvilinear.
- (2) The C57EL/6J strain swam significantly faster than the BALB/cJ strain in the second foot of the straight-away.
- (3) Overall, swimming speed in the second foot appeared to be slower than that in the first foot.
- (4) There was a significant relationship between starting speed and swimming speed in the first foot for the BALB/cJ strain.
- (5) There were qualitative differences in the behavior of the two strains when they were confined in the submerged starting cage, and, to a lesser degree, while swimming in the straight-away.

The results of this investigation are consistent with those reported by Broadhurst (1957). That is to say, the relationship between intensity of motivation and level of performance, in an underwater swimming apparatus, was curvilinear. This relationship occurred only in the first foot of the straight-away. It seems reasonable to assume that the decrement in performance



in the second foot was due to fatigue or some inhibitory effect which was stronger than the imposed motivation.

A comparison of the results of Broadhurst's study (Fig. 1) with those of the present experiment (Fig. 7) reveals that the two functions are extremely similar. In both, there is a linear increase in performance with increasing duration of air deprivation, up to about 8-seconds deprivation, the point at which optimal performance is reached. This degree of similarity is remarkable considering that two different species were used as experimental subjects, i.e., rats and mice, and that Broadhurst used the same Ss under each of the treatment conditions while in the present study separate groups were used. Such consistency points to the efficacy of this experimental procedure as a tool in motivational research.

What is the nature of the experimental findings for the effect of motivation on performance? A search of the literature revealed that a large majority of the studies to date have employed food and water deprivation as the antecedent motivating conditions. The relevance of the results of these studies for the present problem is questionable since the conditions used in the present study are far more aversive. Spence (1956), in discussing the role of motivation in conditioning, divides motivational conditions into two classes which define two types of need states: (1) appetitional needs, and (2) aversive or emotional drive states. He states that:



appetitional needs are specified in terms of maintenance schedules or periods of deprivation of various kinds of environmental objects required to maintain life of the species, e.g., food, water, sex object. Primary emotional drive states are defined in terms of the administration of some noxious or aversive form of environmental stimulation, e.g., electric shock, air puff, heat, or as in the case of the distance receptors, very intense values of light and sound stimuli.

It is obvious that underwater air deprivation is a motivating condition that falls into both of these classes. However, since air deprivation is an extremely noxious form of appetitional need and since underwater submergence is unquestionably aversive to non-aquatic animals such as the mouse, it seems most reasonable to place underwater air deprivation, as a motivating condition, in Spence's second category. Consequently, only studies employing a noxious source of motivation will be examined in detail. With this criterion in mind, the following statement by Brown (1961, p. 96) is sufficient to summarize results of the studies employing appetitional needs:

Studies of the effects of deprivation upon responses instrumental to securing food or water support the conclusion that the speed of these responses and their resistance to extinction tend to be enhanced by privation. Learning curves for different privation levels tend to diverge at a relatively early stage of practice and to maintain a constant separation thereafter, asymptotic performance levels being directly related to deprivation duration from about 2 to perhaps 72 hours, but not beyond.



The most common source of noxious stimulation in motivational studies has been shock intensity. Studies by Amsel (1950) and Campbell and Kraeling (1953) on escape learning, and Kimble (1955) and Brush (1957) on avoidance learning, exemplify the use of this source of drive.

Amsel (1950) compared the running speed of two groups of rats in the middle 4-foot section of a 5-foot alley. The floor of the alley was electrified and the two groups were identical save that one group was given strong shock while the other group was given weak shock. Escape into a wooden floored goal box served as a reinforcement for running. An analysis of running speed at the learning asymptote revealed that the group receiving strong shock ran significantly faster than the group receiving weak shock.

Campbell and Kraeling (1953), on the other hand, in a similar escape situation, found no significant differences in running speed (at the learning asymptote) between three groups of rats shocked at 200, 300 and 400 volts, respectively.

Kimble (1955) conditioned and extinguished four groups of rats in a wheel-turning, avoidance-training apparatus, with a buzzer as the CS and a shock as the UCS. The shock intensities employed were 0.2, 0.5, 1.0, and 2.0 ma, one group of rats being conditioned at each of the four levels of shock used. When the learning curves had reached asymptotes, it was found that response latency decreased as a negatively accelerated



function of shock intensity. That is to say, the speed of the avoidance response increased rapidly up to 0.5 ma and continued to increase at a slower rate for the two higher shock levels. Brush (1957) found an essentially similar result, using dogs as Ss in a delayed conditioning procedure. Employing shock intensities of 0.70, 2.05, 3.10, 4.82, and 5.59 ma, he found that the asymptotic speed of escape and the mean speed of response in extinction were inverted U-shaped functions of shock intensity.

This inverted U-shaped function has been found by another investigator using a different source of noxious stimulation. Kaplan (1952) recorded the rate of responding of white rats in escaping from different intensities of illumination. Rate of responding rose rapidly from 27 to 111 mL., levelled off from 111 to 183 mL., and decreased gradually from 183 to 2312 mL.

Other experimental evidence for the effect of primary emotional drives on response strength has come from studies on eyelid conditioning, in which the source of the noxious stimulation is an air puff. Spence (1956), in Behavior Theory and Conditioning, cites a study by Passey (1948) which showed that the level of eyelid conditioning performance, measured in terms of frequency of conditioned responses in 50 trials, approximated a logarithmic function of the intensity of the air puff. In support of this finding, Spence states that he and his associates "have also obtained evidence which indicates that a



plot of the asymptotic values of frequency curves of eyelid conditioning against the intensity of the air puff provides a negatively accelerated function."

Although the experimental evidence is not in complete agreement, it can generally be concluded that performance rises as the intensity of the motivating agent increases, levels off, and then decreases. In part, the results of the present study support this conclusion.<sup>6</sup>

In seeking theoretical frameworks into which the results of this study could be fitted, the following findings (ignoring strain differences for the moment) must be adequately explained:

- (1) the relationship between drive and performance in the first foot (Fig. 7),
- (2) the decrement in performance in the second foot of the straight-away, and,
- (3) the absence of the relationship between drive and performance in the second foot.

Hull's theory, for one, could account for these phenomena. The obtained relationship between drive and performance, up to 8-seconds deprivation interval, would be predicted by Postulates 6 and 7 of his theory (as summarized by Osgood, 1953, p. 378) which, in essence, state that response strength is a monotonic function of drive. The levelling off in performance between 8 and 12-seconds deprivation could be explained by an inanition

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<sup>6</sup> In terms of the present study, if larger durations of air deprivation were employed, a decrease in performance would be expected.



factor, i.e., anoxia. Hull (1951, p. 38) postulated such a factor in order to explain the down-turning in inverted U-shaped curves, a relationship between motivation and performance which is quite common in the literature. The decrement in performance in the second foot could be due to fatigue-produced inhibition ( $I_R$ ), the buildup of which results in a decrease in "effective reaction potential" ( $S_E^R$ )<sup>7</sup>. Since fatigue intensity (and, hence, performance decrement) is a function of increasing utilization of energy,  $I_R$  builds up more rapidly in organisms exerting the most effort. It follows that the decrement in mean swimming speed between the first and second foot should be an increasing function of the deprivation interval. This is indeed the case (see Fig. 9). This function could account for the absence of the relationship between drive and performance in the second foot.

Hull's formulations can be employed in a second theoretical explanation which is related to the way in which underwater air deprivation differs from the other techniques, i.e., shock, intense illumination, etc., used to elicit a higher state of drive in the organism. When the latter noxious stimuli are applied, the organism is able to react immediately in terms of the instrumental response which leads to escape. In the underwater technique, however, such instrumental behavior is delayed for the duration of the air deprivation interval. In other words, such

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<sup>7</sup> According to Hull, behavior is determined by the amount of effective reaction potential ( $S_E^R$ );  $S_E^R = S_H^R \times D - (I_R + S_I^R)$ , where  $H$  is generalized habit strength,  $D$  is drive,  $I_R$  is fatigue-produced inhibition, and  $S_I^R$  is conditioned inhibition.



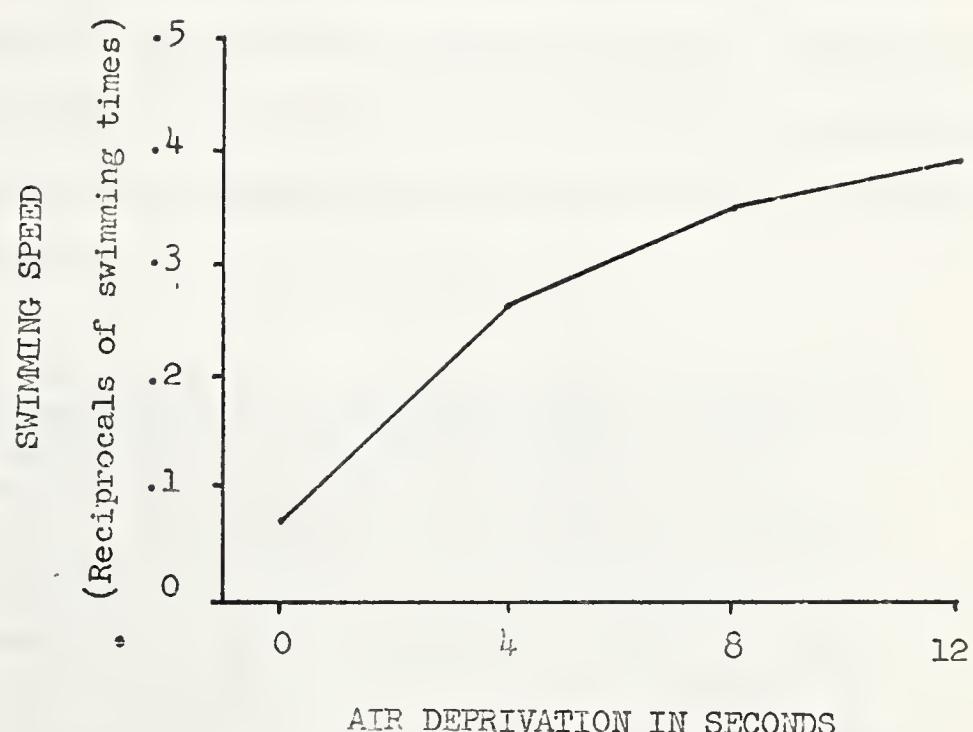


Fig. 9. Decrement in mean swimming speed from the first to the second foot as a function of air deprivation interval. Data for both strains combined.



behavior is momentarily blocked. It has been hypothesized that the delaying or blocking of an instrumental response leads to a state of frustration in the organism (Brown and Farber, 1951; Marx, 1956). Further, it has been experimentally observed that frustration is followed by a momentary increase in drive. If frustration-produced drive is an irrelevant drive, it would combine with the relevant drive, resulting from the air deprivation, to produce a higher level of effective drive.<sup>8</sup> This line of reasoning has been assumed by Brown and Farber in attempting to incorporate the frustration hypothesis into Hullian theory.

In summarizing this approach they say:

According to Hull, irrelevant drives combine with primary drive to produce the effective drive ( $D$ ) that energizes habits into action. On this assumption, the presence of frustration should produce an increment in an organism's effective level of motivation. It follows from this that responses elicited at the time frustration is aroused, or shortly there-after, should be more intense than those elicited when frustration is absent. Moreover, if a response is followed by a reduction in frustration the tendency to perform that response would be strengthened, since drive reduction is assumed to be reinforcing.

In addition, Marx cites two studies (Bernstein, 1954; Holder et al, 1957) which show evidence that, in general, response strength is an increasing function of length of delay. More specifically, Bernstein's study revealed an inverted U-shaped function as the relationship between these variables. Considering

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<sup>8</sup> The effect of frustration upon effective drive can be calculated from Hull's formula,  $\bar{D} = 100 \frac{D + D}{D + 100}$ , where  $\bar{D}$  is effective drive,  $D$  is irrelevant drive, and  $D'$  is relevant (primary) drive.



the present data in the light of frustration theory and the above-mentioned experimental evidence, it is possible that the relevant drive (air deprivation) did not produce the differences in performance between the deprivation groups, but that the irrelevant drive, arising from frustration, was the important determinant.<sup>9</sup> As frustration increased, with increasing interval of confinement in the starting cage, the irrelevant drive would increase, thus resulting in a higher level of effective drive, and, consequently, higher performance. The levelling of performance between 8 and 12-seconds deprivation would be due to the fact that the optimal level of frustration-produced drive has been reached. The decrement in performance in the second half of this straight-away could be due to the dissipation of the irrelevant drive and to the increasing effect of  $I_R$  as this occurred. Both of these phenomena would reduce the level of effective drive. Further, since the Ss which experienced the most frustration would have expended the most effort, it follows that their performance, after the dissipation of the irrelevant drive, would suffer to a greater degree than those subjected to milder frustration-producing conditions. The lack of a

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<sup>9</sup> There is some evidence that supports this statement. If air deprivation per se was a highly significant factor in increasing drive level, one would expect that the 0-sec. deprivation group would swim faster in the second foot, because air deprivation would be more intense here than at the beginning of the first foot. However, in both strains, the average swimming speed was slower in the second foot.



relationship between motivation and performance in the second foot similar to the one obtained in the first foot could be the result of such effects.

Strain differences. A clearly defined strain difference in swimming speed did not occur in the first foot of the straight-away. However, the significant cubic component within the trend of the strain x deprivation interaction suggests that the two strains may react somewhat differently to air deprivation, at least at moderate levels of drive (see Fig. 6). The importance of this finding is questionable due to the small number of subjects used in each treatment group. It is, however, suggestive, and bears investigation in future research.

A significant strain difference did appear in the second foot of the straight-away, the C57BL/6J strain swimming faster than the BALB/cJs (see Fig. 8). The direction of this difference was opposite to the one suggested, i.e., faster swimming speed on the part of the highly emotional BALB/cJ strain. Since these strains differ as to many organismic variables, there is little basis for determining the causal factors which produced this difference in performance. Certainly, the higher activity level of the C57BL/6J strain (as shown by Thompson) is one possible explanation, but this is just conjecture.

As in the case of the first foot, the importance of the strain difference in the second foot is questionable. Although the main effect of strain was significant, the ensuing comparison of individual means revealed that the only significant difference



occurred between the strain means in the 8-second deprivation interval. This would suggest that the obtained overall strain difference is of little practical importance.

The most clearly noticeable difference between the strains occurred during the deprivation intervals, i.e., while the Ss were confined in the starting cage. As mentioned previously, the C57BL/6J Ss were highly active and randomly explored every corner of the cage. On the other hand, the behavior of the BALB/cJ Ss was much more directed, in terms of the appropriate response. That is to say, they remained near the door and clawed at it vigorously until it was opened.<sup>10</sup> Considering this behavioral difference in a more general way, it may be that in highly stressful frustrating situations the C57BL/6J strain reacts with an increase in random activity, whereas the behavior of the BALB/cJ strain becomes stereotyped. Another way to express this would be to say that under stress and frustration there is an increase in competing response tendency for the C57BL/6J strain, and a decrease for the BALB/cJ strain. However, in the present study, such responses do not seem to interfere with performance in any systematic way. A glance at the learning curves for starting in Fig. 3 seems to support this contention.<sup>11</sup> It would appear that in a simple

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<sup>10</sup> Obviously, these observations apply only to Ss under 4, 8, and 12-second deprivation.

<sup>11</sup> This data was not subjected to statistical analysis because of the ad hoc nature of such a test. Also, in making this statement, the learning curves for the 0-second deprivation groups have been ignored for the reasons stated in the first footnote.



learning situation, such as the present one, where the S is called upon to repeat a constant response which is appropriate, performance is but little affected by diverse modes of behavior prior to the execution of that response. However, it would be reasonable to infer that in a more complex learning problem where a switch to a new appropriate response is required, Ss of the C57BL/6J strain would be able to modify their behavior much more rapidly than the BALB/cJs. Such a hypothesis is worthy of investigation in future research.

The relationship between starting scores and swimming speed scores in the first foot may reflect an aspect of behavior similar to that discussed above. For the C57BL/6J strain, a non-significant correlation ( $r = .06$ ) was obtained between these two variables, whereas the correlation obtained for the BALB/cJ strain ( $r = .70$ ) was highly significant, and positive. For the BALB/cJ strain, this means that the faster the emergence from the starting cage, the better the performance in the first foot. To make a causal assumption about this relationship, it would appear that the performance of the BALB/cJ strain, in a situation, is, to a considerable degree, determined by the ease with which the Ss adapted to the events immediately preceding that situation. In other words, these Ss seem to be behaviorally rigid to the degree that they cannot easily alter their behavior when the stimulus situation demands such changes. The C57BL/6J Ss, on the other hand, appear to be much more flexible, and, consequently, their behavior is more situationally determined.



This hypothesized flexibility-rigidity behavioral dichotomy may be reflected in the learning curves. From a visual inspection of Figures 3, 4, and 5, it would appear that there is a greater variability of response to the different levels of deprivation in the C57BL/6J strain than in the BALB/cJ strain. The significance of this difference was not tested statistically due to the ad hoc nature of such a test. These statements are speculative but they might be provocative for further research in this area.



SUMMARY AND CONCLUSIONS

To determine the relationship between intensity of motivation and performance, two strains of mice, C57BL/6J and BALB/cJ were run in an underwater straight-away. Four levels of air deprivation were used as sources of motivation. Underwater swimming speed was the measure of performance.

The results showed that there was a significant curvilinear relationship between level of air deprivation and swimming speed, in the first half of the straight-away. That is to say, swimming speed increased almost linearly, with increasing duration of air deprivation, up to an optimum point at which swimming speed levelled off despite further increases in deprivation. In general, this finding is in agreement with the results of other studies which have investigated the nature of the function relating motivation to performance.

In the second half of the straight-away, air deprivation had no significant effect on swimming speed. A theoretical integration of these findings was attempted in terms of Hull's system and a frustration hypothesis.

Certain performance and behavioral differences occurred between the two strains. In the first foot of the straight-away, there was some evidence that the two strains perform somewhat differently at moderate levels of drive. In the second foot of the straight-away, the C57BL/6J Ss swam significantly faster than the Ss of the BALB/cJ strain. Moreover, for the BALB/cJ strain, there was a significant positive relationship between starting speed and



swimming speed in the first foot. Behaviorally, the two strains reacted quite differently while confined in the starting cage, i.e., during the air deprivation intervals. The C57BL/6J Ss were very active, and randomly explored every corner of the starting cage. The BALB/cJ Ss, on the other hand, positioned themselves in front of the starting cage door and clawed at it vigorously throughout the deprivation interval. In the light of the above findings, a hypothesis, which describes the BALB/cJs as being behaviorally rigid and the C57BL/6Js as being behaviorally flexible, was presented. The major point in this hypothesis is that the performance of the BALB/cJ strain is largely determined by the events preceding the performance, whereas, the performance of the C57BL/6J strain is more situationally determined.



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Appendix 1. Illustration of the Amperometric



<u>Source of Variation</u>	<u>Sum of Squares</u>	<u>df</u>	<u>Mean Square</u>	<u>F</u>
Strain	2.4035	1	2.4035	9.02**
Deprivation	.9976	3	.3325	1.25
Strain x deprivation	13.5708	3	4.5236	16.97**
Error (a)	14.9235	56	.2665	
Trials	6.5352	5	1.3070	29.70**
Strain x trials	.9262	5	.1852	4.21**
Deprivation x trials	.7169	15	.0478	1.09
Strain x dep. x trials	1.0327	15	.0688	1.56
Error (b)	<u>12.3141</u>	<u>280</u>	.0440	
	53.4205	383		
Linear Components:				
Trials	5.8740	1	5.8740	133.50**
Strain x trials	.2282	1	.2282	5.19*
Deprivation x trials	.2268	3	.0756	1.72
Strain x dep. x trials	.7664	3	.2555	5.81**
Quadratic Components:				
Trials	.6253	1	.6253	14.21**
Strain x trials	.0272	1	.0272	=
Deprivation x trials	.0918	3	.0306	=
Strain x dep. x trials	.1464	3	.0488	1.11
Error (b)	12.3141	280	.0440	

\* p < .025

\*\* p < .005

APPENDIX 2. Trend analysis of variance of learning curves in starting.



<u>Source of Variation</u>	<u>Sum of Squares</u>	<u>df</u>	<u>Mean Square</u>	<u>F</u>
Strain	.2715	1	.2715	2.44
Deprivation	4.5960	3	1.6520	14.25*
Strain x deprivation	.6311	3	.2104	1.82
Error (a)	6.4880	56	.1159	
 Trials	.2561	5	.0512	5.95*
Strain x trials	.1740	5	.0348	4.05*
Deprivation x trials	.3318	15	.0221	2.57*
Strain x dep. x trials	.4550	15	.0303	3.52*
Error (b)	<u>2.4162</u>	<u>280</u>	.0086	
	15.6197	383		

## Linear Components:

Trials	.1455	1	.1455	16.92*
Strain x trials	.1638	1	.1638	19.05*
Deprivation x trials	.2507	3	.0836	9.72*
Strain x dep. x trials	.3433	3	.1144	13.30*

## Quadratic Components:

Trials	.0085	1	.0085	-
Strain x trials	.0050	1	.0050	-
Deprivation x trials	.0240	3	.0080	-
Strain x dep. x trials	.0506	3	.0169	1.97
Error (b)	2.4162	280	.0086	

\*p &lt; .005

APPENDIX 3. Trend analysis of variance of learning curves in the first foot of the underwater straight-away.



<u>Source of Variation</u>	<u>Sum of Squares</u>	<u>df</u>	<u>Mean Square</u>	<u>F</u>
Strain	.5513	1	.5513	15.40**
Deprivation	.1946	3	.0649	1.81
Strain x deprivation	.0471	3	.0157	-
Error (a)	2.0046	56	.0358	
 Trials	 .0660	 5	 .0132	 3.00*
Strain x trials	.0726	5	.0145	3.30*
Deprivation x trials	.0850	15	.0057	1.30
Strain x dep. x trials	.1520	15	.0101	2.30**
Error (b)	<u>1.2316</u>	<u>280</u>	<u>.0044</u>	
	4.4048	383		
 Linear Components:				
Trials	.0364	1	.0364	8.27**
Strain x trials	.0393	1	.0393	8.93**
Deprivation x trials	.0652	3	.0217	4.93**
Strain x dep. x trials	.1239	3	.0413	9.39**
 Quadratic Components:				
Trials	.0128	1	.0128	2.91
Strain x trials	.0016	1	.0016	-
Deprivation x trials	.0069	3	.0023	-
Strain x dep. x trials	.0068	3	.0023	-
Error (b)	1.2316	280	.0044	

\* p < .01

\*\* p < .005

APPENDIX 4 . Trend analysis of variance of learning curves in the second foot of the underwater straight-away.



## AIR DEPRIVATION INTERVAL

	0	4	8	12
C57BL/6J SS	.66	.42	1.20	.79
1.	.47	.88	1.21	1.32
2.	.73	.96	.69	1.02
3.	.58	.83	1.07	1.02
4.	.51	.80	1.22	.96
5.	.60	.79	.96	.85
6.	.73	.59	.75	.87
7.	.60	.72	1.08	.68
8.				
Σ	4.88	5.99	8.18	7.51

## AIR DEPRIVATION INTERVAL

	0	4	8	12
BALB/cJ SS	.39	.84	.91	.97
1.	.72	1.01	.78	.60
2.	.75	1.12	.72	.95
3.	.52	1.10	.79	1.08
4.	.56	.70	1.24	1.08
5.	.53	.57	.75	.84
6.	.60	1.08	.76	.97
7.	.60	.68	1.06	1.17
8.				
Σ	4.67	7.10	7.01	7.66

Appendix 5. Swimming speed scores (reciprocals of swimming times) for both strains, C57BL/6J and BALB/cJ, in the first foot. Values are of performance averaged over trial Blocks 5 and 6. Each cell represents the score of a single S.



## AIR DEPRIVATION INTERVAL

C57BL/6J Ss

	0	4	8	12
1.	.62	.41	.52	.54
2.	.51	.53	.72	.59
3.	.46	.67	.49	.53
4.	.44	.62	.67	.57
5.	.39	.63	.80	.65
6.	.47	.54	.73	.66
7.	.71	.60	.57	.55
8.	.52	.54	.68	.49
	4.12	4.54	5.28	4.78

## AIR DEPRIVATION INTERVAL

BALE/cJ Ss

	0	4	8	12
1.	.39	.52	.46	.39
2.	.55	.51	.52	.37
3.	.67	.73	.53	.58
4.	.46	.54	.55	.58
5.	.56	.50	.69	.46
6.	.65	.46	.43	.45
7.	.52	.60	.55	.59
8.	.46	.43	.59	.70
	4.26	4.29	4.32	4.12

Appendix 6. Swimming speed scores (reciprocals of swimming times) for both strains, C57BL/6J and BALE/cJ, in the second foot. Values are of performance averaged over trial Blocks 5 and 6. Each cell represents the score of a single S.



## AIR DEPRIVATION INTERVAL

	0	4	8	12
1.	1.95	1.33	1.30	1.26
2.	1.37	1.42	1.82	1.40
3.	1.95	1.44	1.40	1.56
4.	1.32	1.50	1.80	1.20
5.	1.86	1.12	1.76	1.35
6.	1.52	.88	1.61	1.06
7.	2.00	1.29	1.23	1.12
8.	1.96	1.28	1.65	1.00
$\Sigma$	13.93	10.26	12.57	9.95

## AIR DEPRIVATION INTERVAL

	0	4	8	12
1.	.68	1.38	1.57	1.60
2.	1.44	1.52	1.28	1.26
3.	1.52	1.48	1.20	1.35
4.	1.34	1.64	1.42	1.53
5.	1.31	1.01	1.72	1.17
6.	.84	1.41	1.19	1.47
7.	.74	1.66	1.59	1.69
8.	1.56	1.04	1.59	1.76
$\Sigma$	9.43	11.14	11.56	11.83

Appendix 7. Swimming speed scores (reciprocals of swimming times) for both strains, C57BL/6J and BALB/cJ, in starting. Values are of performance averaged over trial Blocks 5 and 6. Each cell represents the score of a single S.









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